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(54) **METHODS AND SYSTEMS FOR HUMIDITY DETECTION VIA AN EXHAUST GAS SENSOR**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 44 days.

This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

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(51) **Int. Cl.**

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F02D 41/12	(2006.01)
F02D 41/02	(2006.01)
F02P 5/145	(2006.01)
F02D 41/14	(2006.01)

(52) **U.S. Cl.**

CPC ***F01N 11/007*** (2013.01); ***F02D 41/0235*** (2013.01); ***F02D 41/123*** (2013.01); ***F02D 41/1454*** (2013.01); ***F02P 5/145*** (2013.01); *F01N 2560/028* (2013.01); *F01N 2560/12* (2013.01); *F02D 2041/1472* (2013.01); *F02D 2200/0418* (2013.01)

(58) **Field of Classification Search**

CPC F01N 11/007; F01N 2560/028; F01N 2560/12; F02D 41/02; F02D 41/0235; F02D 41/123; F02D 41/1454; F02D 2200/0418; F02D 2041/1472; F02P 5/145

USPC 60/274, 276, 278, 285; 73/114.72, 73/114.73

See application file for complete search history.

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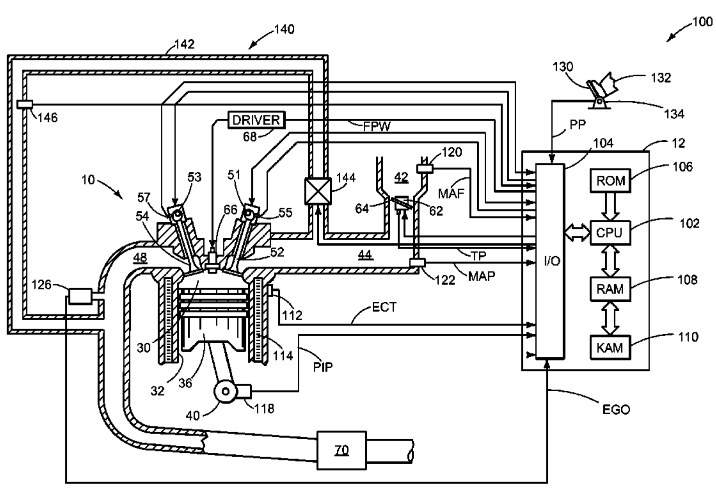
(57) **ABSTRACT**

Various methods and system are described for determining ambient humidity via an exhaust gas sensor disposed in an exhaust system of an engine. In one example, a reference voltage of the sensor is modulated between a first and second voltage during non-fueling conditions of the engine. The ambient humidity is determined based on an average change in pumping current while the voltage is modulated.

20 Claims, 5 Drawing Sheets



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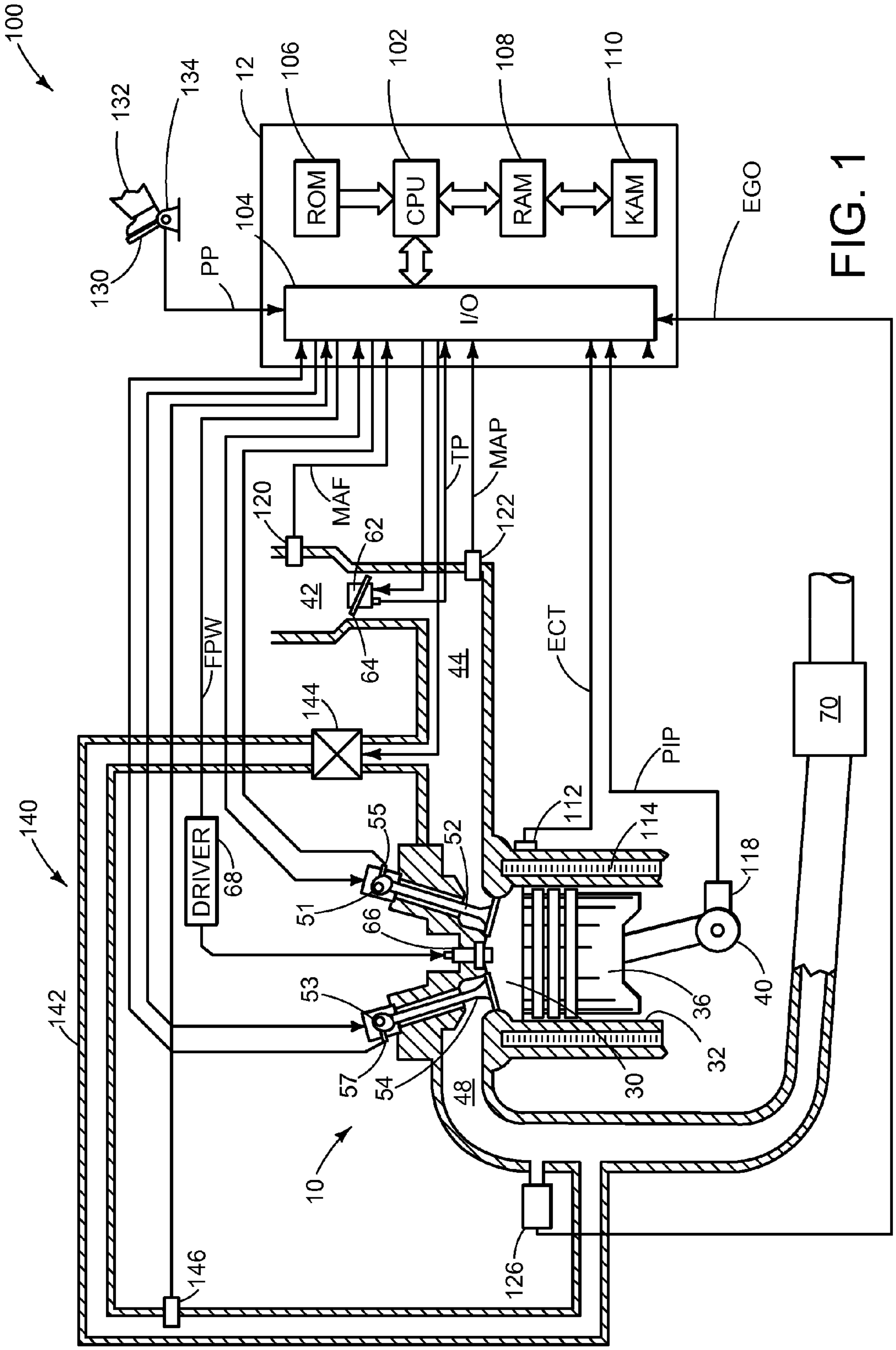
100
132
134
130
PP
12
104
106
102
108
110
ROM
CPU
RAM
KAM
I/O
EGO
120
MAF
TP
MAP
62
122
42
64
44
ECT
FPW
144
140
DRIVER
68
55
52
112
114
118
51
66
53
40
36
32
30
57
54
48
10
142
146
126
70
PIP

FIG. 1

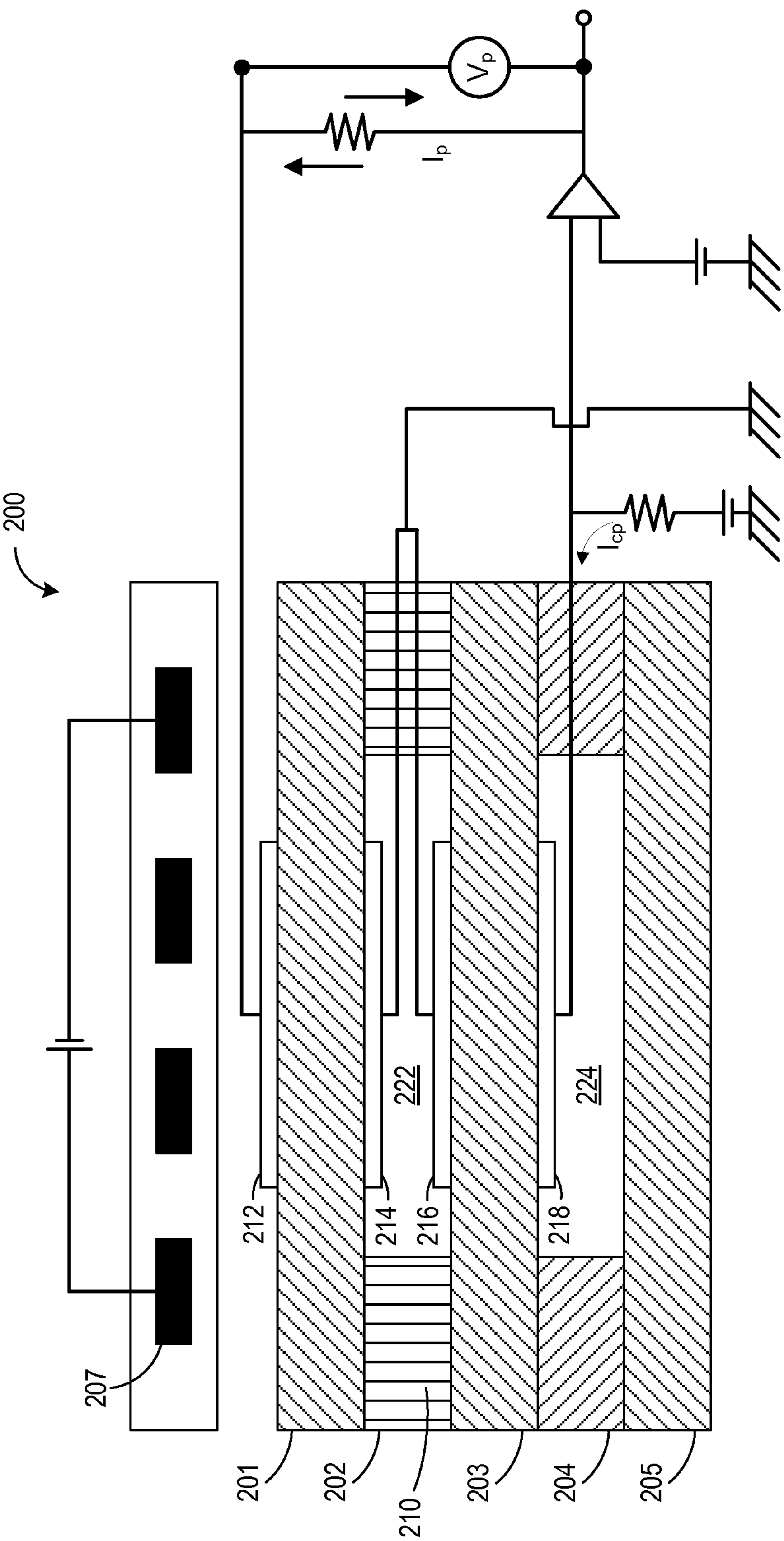

FIG. 2

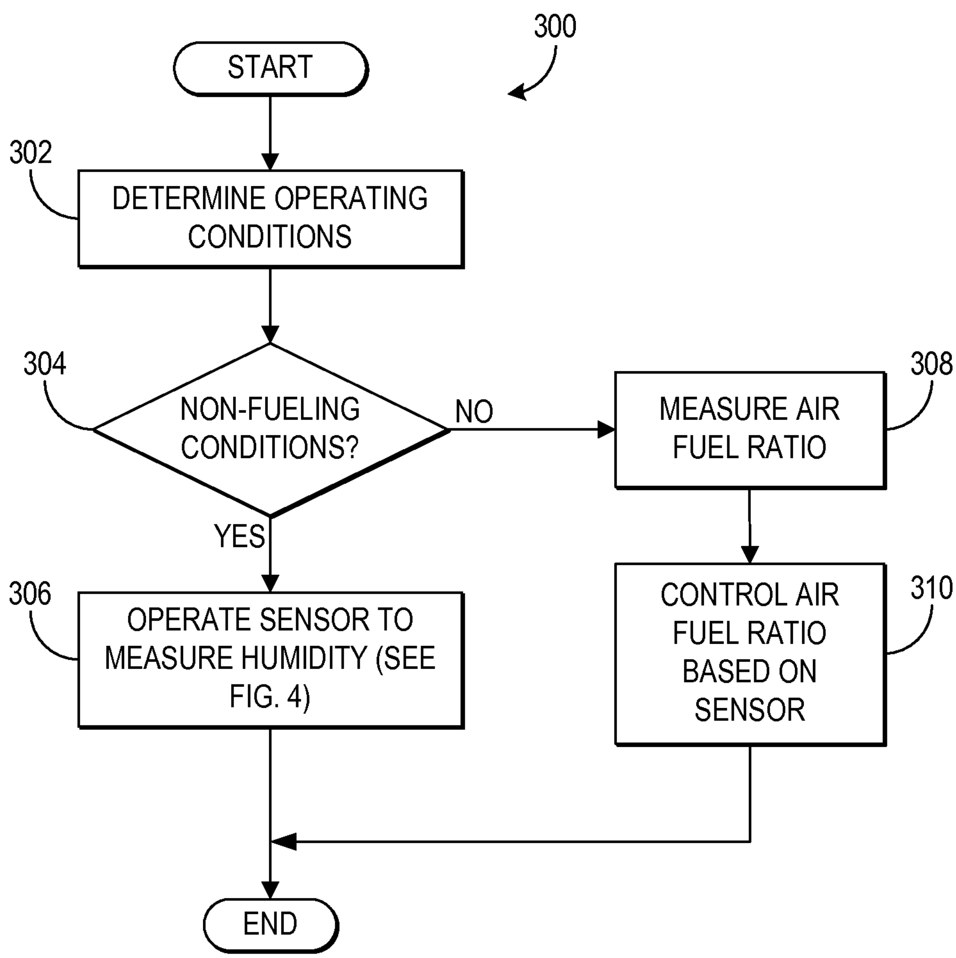
300
START
302
DETERMINE OPERATING CONDITIONS
304
NON-FUELING CONDITIONS?
NO
YES
306
OPERATE SENSOR TO MEASURE HUMIDITY (SEE FIG. 4)
308
MEASURE AIR FUEL RATIO
310
CONTROL AIR FUEL RATIO BASED ON SENSOR
END

FIG. 3

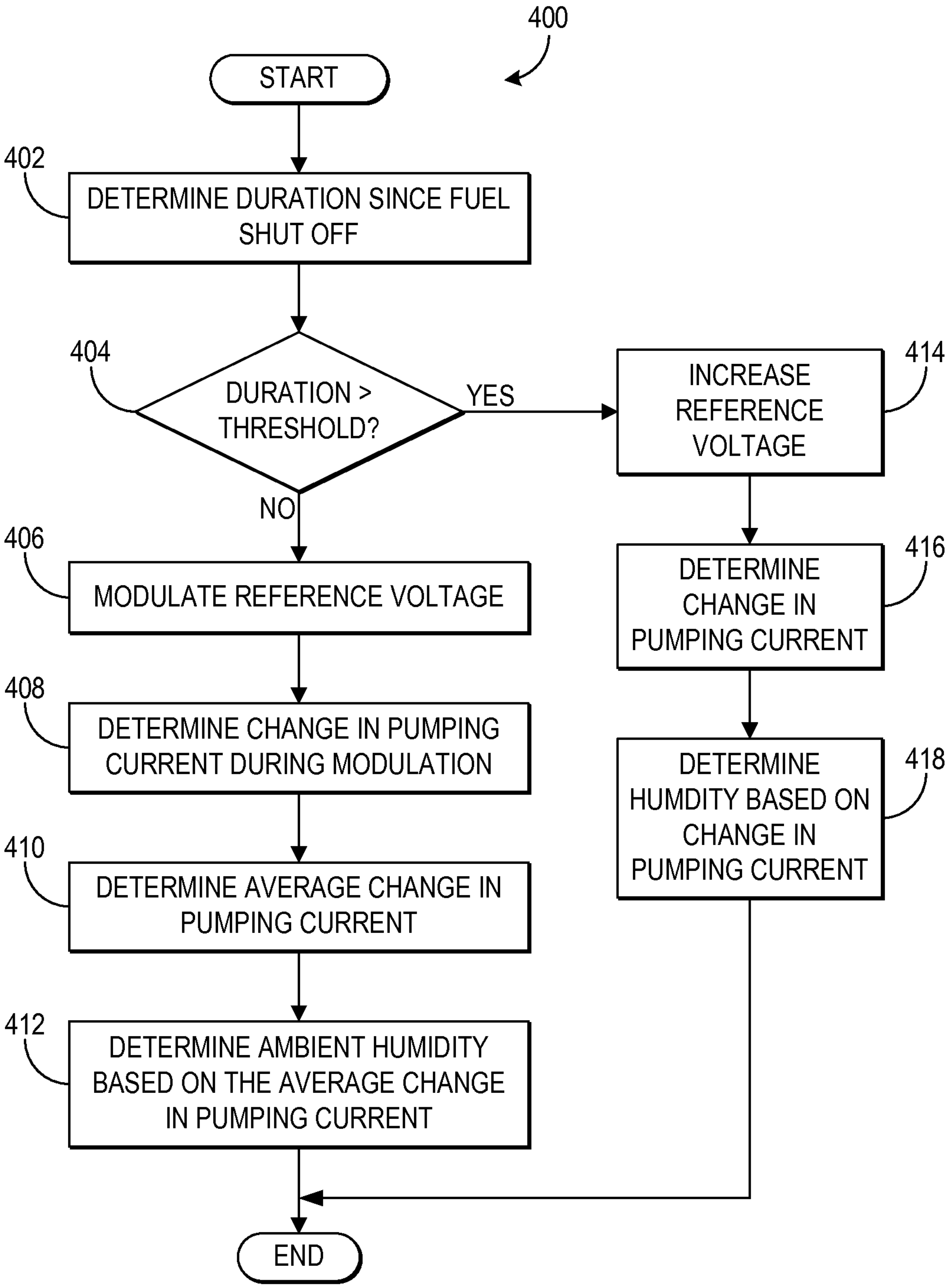
400
START
402
DETERMINE DURATION SINCE FUEL SHUT OFF
404
DURATION > THRESHOLD?
YES
NO
414
INCREASE REFERENCE VOLTAGE
406
MODULATE REFERENCE VOLTAGE
416
DETERMINE CHANGE IN PUMPING CURRENT
408
DETERMINE CHANGE IN PUMPING CURRENT DURING MODULATION
418
DETERMINE HUMDITY BASED ON CHANGE IN PUMPING CURRENT
410
DETERMINE AVERAGE CHANGE IN PUMPING CURRENT
412
DETERMINE AMBIENT HUMIDITY BASED ON THE AVERAGE CHANGE IN PUMPING CURRENT
END

FIG. 4

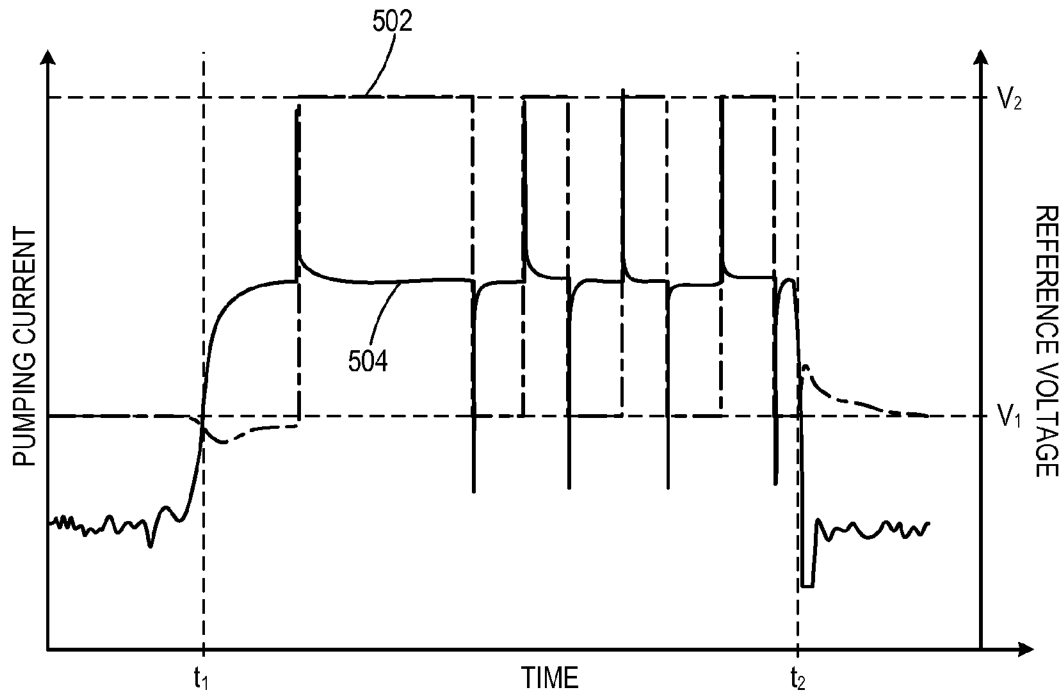
502
PUMPING CURRENT
REFERENCE VOLTAGE
V_2
V_1
504
t_1
TIME
t_2

FIG. 5

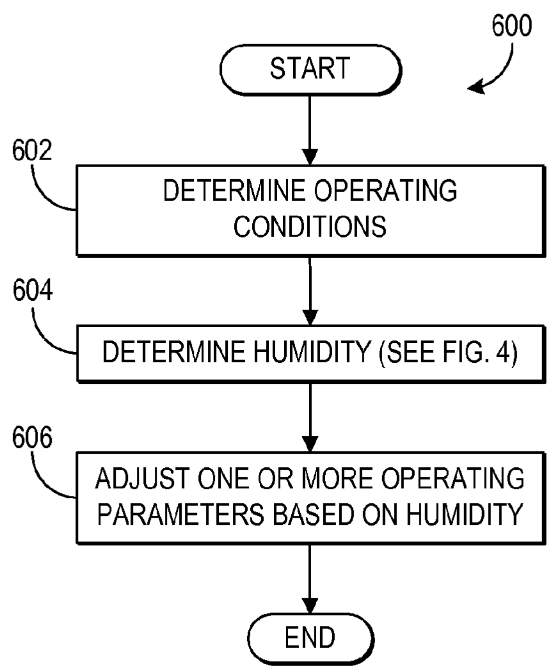
600
START
602
DETERMINE OPERATING CONDITIONS
604
DETERMINE HUMIDITY (SEE FIG. 4)
606
ADJUST ONE OR MORE OPERATING PARAMETERS BASED ON HUMIDITY
END

FIG. 6

METHODS AND SYSTEMS FOR HUMIDITY DETECTION VIA AN EXHAUST GAS SENSOR

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 13/745,639, entitled "METHODS AND SYSTEMS FOR HUMIDITY DETECTION VIA AN EXHAUST GAS SENSOR," filed on Jan. 18, 2013, now U.S. Pat. No. 8,857,155, the entire contents of which are hereby incorporated by reference for all purposes.

TECHNICAL FIELD

The present application relates generally to ambient humidity detection via an exhaust gas sensor coupled in an exhaust system of an internal combustion engine.

BACKGROUND AND SUMMARY

During engine non-fueling conditions in which at least one intake valve and one exhaust valve are operating, such as deceleration fuel shut off (DFSO), ambient air may flow through engine cylinders and into the exhaust system. In some examples, an exhaust gas sensor may be utilized to determine ambient humidity during the engine non-fueling conditions. It may take a long time for the exhaust flow to be devoid of hydrocarbons during the engine non-fueling conditions, however, and, as such, an accurate indication of ambient humidity may be delayed.

The inventors herein have recognized the above issue and have devised an approach to at least partially address it. Thus, a method for an engine system which includes an exhaust gas sensor is disclosed. In one example, the method includes, during engine non-fueling conditions, where at least one intake valve and one exhaust valve are operating: modulating a reference voltage of the sensor; generating an ambient humidity based on a corresponding change in pumping current of the sensor; and, during selected operating conditions, adjusting an engine operating parameter based on the ambient humidity.

By modulating the reference voltage and determining the change in pumping current while the air fuel ratio is still changing during non-fueling conditions, such as DFSO, the effect of the changing air fuel ratio may be nullified. As such, the ambient humidity may be determined in a shorter amount of time, as the exhaust air fuel ratio does not have to be stable before an accurate indication of ambient humidity may be determined.

It should be understood that the summary above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an example embodiment of a combustion chamber in an engine system including an exhaust system and an exhaust gas recirculation system.

FIG. **2** shows a schematic diagram of an example exhaust gas sensor.

FIG. **3** is a flow chart illustrating a routine for determining a measurement mode of an exhaust gas sensor.

FIG. **4** is a flow chart illustrating a routine for determining ambient humidity based on an exhaust gas sensor.

FIG. **5** shows a graph illustrating reference voltage and pumping current of an exhaust gas sensor during deceleration fuel cut off.

FIG. **6** is a flow chart illustrating a routine for adjusting engine operating parameters based on an ambient humidity generated by an exhaust gas sensor.

DETAILED DESCRIPTION

The following description relates to methods and systems for an engine system with an exhaust gas sensor. In one example, a method comprises, during engine non-fueling conditions, where at least one intake valve and one exhaust valve are operating: modulating a reference voltage of the sensor, generating an ambient humidity based on a corresponding change in pumping current of the sensor, and adjusting an engine operating parameter based on the ambient humidity. As an example, the change in pumping current may be averaged over a duration during the non-fueling conditions. In this way, accuracy of the humidity determination based on the change in pumping current may be improved, for example. Further, the ambient humidity determination may be made in a reduced amount of time, as averaging the change in pumping current reduces the effect of a changing air fuel ratio. Once the ambient humidity is determined, one or more engine operating parameters may be adjusted during fueling conditions, for example. In one example, an amount of exhaust gas recirculation (EGR) is adjusted based on the ambient humidity. In this way, the system can nullify the effect of the changing air fuel ratio by modulating the reference voltage.

FIG. **1** is a schematic diagram showing one cylinder of a multi-cylinder engine **10** in an engine system **100**, which may be included in a propulsion system of an automobile. The engine **10** may be controlled at least partially by a control system including a controller **12** and by input from a vehicle operator **132** via an input device **130**. In this example, the input device **130** includes an accelerator pedal and a pedal position sensor **134** for generating a proportional pedal position signal PP. A combustion chamber (i.e., cylinder) **30** of the engine **10** may include combustion chamber walls **32** with a piston **36** positioned therein. The piston **36** may be coupled to a crankshaft **40** so that reciprocating motion of the piston is translated into rotational motion of the crankshaft. The crankshaft **40** may be coupled to at least one drive wheel of a vehicle via an intermediate transmission system. Further, a starter motor may be coupled to the crankshaft **40** via a flywheel to enable a starting operation of the engine **10**.

The combustion chamber **30** may receive intake air from an intake manifold **44** via an intake passage **42** and may exhaust combustion gases via an exhaust passage **48**. The intake manifold **44** and the exhaust passage **48** can selectively communicate with the combustion chamber **30** via respective intake valve **52** and exhaust valve **54**. In some embodiments, the combustion chamber **30** may include two or more intake valves and/or two or more exhaust valves.

In this example, the intake valve **52** and exhaust valve **54** may be controlled by cam actuation via respective cam actuation systems **51** and **53**. The cam actuation systems **51** and **53** may each include one or more cams and may utilize one or more of cam profile switching (CPS), variable cam timing (VCT), variable valve timing (VVT), and/or variable valve lift (VVL) systems that may be operated by the controller **12** to vary valve operation. The position of the intake valve **52** and exhaust valve **54** may be determined by position sensors **55** and **57**, respectively. In alternative embodiments, the intake valve **52** and/or exhaust valve **54** may be controlled by electric valve actuation. For example, the cylinder **30** may alternatively include an intake valve controlled via electric valve actuation and an exhaust valve controlled via cam actuation including CPS and/or VCT systems.

A fuel injector **66** is shown coupled directly to combustion chamber **30** for injecting fuel directly therein in proportion to the pulse width of signal FPW received from the controller **12** via an electronic driver **68**. In this manner, the fuel injector **66** provides what is known as direct injection of fuel into the combustion chamber **30**. The fuel injector may be mounted in the side of the combustion chamber or in the top of the combustion chamber (as shown), for example. Fuel may be delivered to the fuel injector **66** by a fuel system (not shown) including a fuel tank, a fuel pump, and a fuel rail. In some embodiments, the combustion chamber **30** may alternatively or additionally include a fuel injector arranged in the intake manifold **44** in a configuration that provides what is known as port injection of fuel into the intake port upstream of the combustion chamber **30**.

The intake passage **42** may include a throttle **62** having a throttle plate **64**. In this particular example, the position of throttle plate **64** may be varied by the controller **12** via a signal provided to an electric motor or actuator included with the throttle **62**, a configuration that is commonly referred to as electronic throttle control (ETC). In this manner, the throttle **62** may be operated to vary the intake air provided to the combustion chamber **30** among other engine cylinders. The position of the throttle plate **64** may be provided to the controller **12** by a throttle position signal TP. The intake passage **42** may include a mass air flow sensor **120** and a manifold air pressure sensor **122** for providing respective signals MAF and MAP to the controller **12**.

An exhaust gas sensor **126** is shown coupled to the exhaust passage **48** upstream of an emission control device **70**. The sensor **126** may be any suitable sensor for providing an indication of exhaust gas air/fuel ratio such as a linear oxygen sensor or UEGO (universal or wide-range exhaust gas oxygen), a two-state oxygen sensor or EGO, a HEGO (heated EGO), a NO_x, HC, or CO sensor. The emission control device **70** is shown arranged along the exhaust passage **48** downstream of the exhaust gas sensor **126**. The device **70** may be a three way catalyst (TWC), NO_x trap, various other emission control devices, or combinations thereof. In some embodiments, during operation of the engine **10**, the emission control device **70** may be periodically reset by operating at least one cylinder of the engine within a particular air/fuel ratio.

Further, in the disclosed embodiments, an exhaust gas recirculation (EGR) system **140** may route a desired portion of exhaust gas from the exhaust passage **48** to the intake manifold **44** via an EGR passage **142**. The amount of EGR provided to the intake manifold **44** may be varied by the controller **12** via an EGR valve **144**. Further, an EGR sensor **146** may be arranged within the EGR passage **142** and may provide an indication of one or more of pressure, temperature, and constituent concentration of the exhaust gas. Under some conditions, the EGR system **140** may be used to regulate the temperature of the air and fuel mixture within the combustion chamber, thus providing a method of controlling the timing of ignition during some combustion modes. Further, during some conditions, a portion of combustion gases may be retained or trapped in the combustion chamber by controlling exhaust valve timing, such as by controlling a variable valve timing mechanism.

The controller **12** is shown in FIG. **1** as a microcomputer, including a microprocessor unit **102**, input/output ports **104**, an electronic storage medium for executable programs and calibration values shown as read only memory chip **106** in this particular example, random access memory **108**, keep alive memory **110**, and a data bus. The controller **12** may receive various signals from sensors coupled to the engine **10**, in addition to those signals previously discussed, including measurement of inducted mass air flow (MAF) from the mass air flow sensor **120**; engine coolant temperature (ECT) from a temperature sensor **112** coupled to a cooling sleeve **114**; a profile ignition pickup signal (PIP) from a Hall effect sensor **118** (or other type) coupled to crankshaft **40**; throttle position (TP) from a throttle position sensor; and absolute manifold pressure signal, MAP, from the sensor **122**. Engine speed signal, RPM, may be generated by the controller **12** from signal PIP. Manifold pressure signal MAP from a manifold pressure sensor may be used to provide an indication of vacuum, or pressure, in the intake manifold. Note that various combinations of the above sensors may be used, such as a MAF sensor without a MAP sensor, or vice versa. During stoichiometric operation, the MAP sensor can give an indication of engine torque. Further, this sensor, along with the detected engine speed, can provide an estimate of charge (including air) inducted into the cylinder. In one example, the sensor **118**, which is also used as an engine speed sensor, may produce a predetermined number of equally spaced pulses every revolution of the crankshaft.

The storage medium read-only memory **106** can be programmed with computer readable data representing non-transitory instructions executable by the processor **102** for performing the methods described below as well as other variants that are anticipated but not specifically listed.

As described above, FIG. **1** shows only one cylinder of a multi-cylinder engine, and each cylinder may similarly include its own set of intake/exhaust valves, fuel injector, spark plug, etc.

FIG. **2** shows a schematic view of an example embodiment of an exhaust gas sensor, such as a UEGO sensor **200** configured to measure a concentration of oxygen (O_2) in an exhaust gas stream. The sensor **200** may operate as the exhaust gas sensor **126** described above with reference to FIG. **1**, for example. The sensor **200** comprises a plurality of layers of one or more ceramic materials arranged in a stacked configuration. In the embodiment of FIG. **2**, five ceramic layers are depicted as layers **201**, **202**, **203**, **204**, and **205**. These layers include one or more layers of a solid electrolyte capable of conducting ionic oxygen. Examples of suitable solid electrolytes include, but are not limited to, zirconium oxide-based materials. Further, in some embodiments such as that shown in FIG. **2**, a heater **207** may be disposed in thermal communication with the layers to increase the ionic conductivity of the layers. While the depicted UEGO sensor **200** is formed from five ceramic layers, it will be appreciated that the UEGO sensor may include other suitable numbers of ceramic layers.

The layer **202** includes a material or materials creating a diffusion path **210**. The diffusion path **210** is configured to introduce exhaust gases into a first internal cavity **222** via diffusion. The diffusion path **210** may be configured to allow one or more components of exhaust gases, including but not limited to a desired analyte (e.g., O_2), to diffuse into the internal cavity **222** at a more limiting rate than the analyte can be pumped in or out by pumping electrodes pair **212** and **214**. In this manner, a stoichiometric level of O_2 may be obtained in the first internal cavity **222**.

The sensor **200** further includes a second internal cavity **224** within the layer **204** separated from the first internal cavity **222** by the layer **203**. The second internal cavity **224** is configured to maintain a constant oxygen partial pressure equivalent to a stoichiometric condition, e.g., an oxygen level present in the second internal cavity **224** is equal to that which the exhaust gas would have if the air-fuel ratio was stoichiometric. The oxygen concentration in the second internal cavity **224** is held constant by pumping current I_{cp}. Herein, the second internal cavity **224** may be referred to as a reference cell.

A pair of sensing electrodes **216** and **218** is disposed in communication with first internal cavity **222** and the reference cell **224**. The sensing electrodes pair **216** and **218** detects a concentration gradient that may develop between the first internal cavity **222** and the reference cell **224** due to an oxygen concentration in the exhaust gas that is higher than or lower than the stoichiometric level. A high oxygen concentration may be caused by a lean exhaust gas mixture, while a low oxygen concentration may be caused by a rich mixture, for example.

The pair of pumping electrodes **212** and **214** is disposed in communication with the internal cavity **222**, and is configured to electrochemically pump a selected gas constituent (e.g., O_2) from the internal cavity **222** through the layer **201** and out of the sensor **200**. Alternatively, the pair of pumping electrodes **212** and **214** may be configured to electrochemically pump a selected gas through the layer **201** and into the internal cavity **222**. Herein, the pumping electrodes pair **212** and **214** may be referred to as an O_2 pumping cell.

The electrodes **212**, **214**, **216**, and **218** may be made of various suitable materials. In some embodiments, the electrodes **212**, **214**, **216**, and **218** may be at least partially made of a material that catalyzes the dissociation of molecular oxygen. Examples of such materials include, but are not limited to, electrodes containing platinum and/or gold.

The process of electrochemically pumping the oxygen out of or into the internal cavity **222** includes applying an electric current I_p across the pumping electrodes pair **212** and **214**. The pumping current I_p applied to the O_2 pumping cell pumps oxygen into or out of the first internal cavity **222** in order to maintain a stoichiometric level of oxygen in the cavity pumping cell. The pumping current I_p is proportional to the concentration of oxygen in the exhaust gas. Thus, a lean mixture will cause oxygen to be pumped out of the internal cavity **222** and a rich mixture will cause oxygen to be pumped into the internal cavity **222**.

A control system (not shown in FIG. **2**) generates the pumping voltage signal V_p as a function of the intensity of the pumping current I_p required to maintain a stoichiometric level within the first internal cavity **222**.

It should be appreciated that the UEGO sensor described herein is merely an example embodiment of a UEGO sensor, and that other embodiments of UEGO sensors may have additional and/or alternative features and/or designs.

FIGS. **3**, **4**, and **6** show flow charts illustrating routines for an exhaust gas sensor and an engine system, respectively. For example, the routine shown in FIG. **3** determines whether the sensor should be operated to measure exhaust gas oxygen concentration or ambient humidity based on fueling conditions of the engine. The routine shown in FIG. **4** determines the ambient humidity based on an exhaust gas sensor, such as the exhaust gas sensor **200** described above with reference to FIG. **2**. FIG. **6** shows a routine for adjusting an engine operating parameter based on the ambient humidity determined via the routine shown in FIG. **3**.

FIG. **3** shows a flow chart illustrating a routine **300** for controlling an exhaust gas sensor, such as the exhaust gas sensor described above with reference to FIG. **2** and positioned as shown in FIG. **1**, based on engine fueling conditions. Specifically, the routine determines if the engine system is operating under non-fueling conditions and adjusts a measurement mode of the sensor accordingly. For example, during non-fueling conditions, the sensor is operated in a mode to determine ambient humidity and during fueling conditions, the sensor is operated in a mode to measure exhaust gas oxygen concentration to determine air fuel ratio.

At **302** of routine **300** in FIG. **3**, engine operating conditions are determined. As non-limiting examples, the engine operating conditions may include actual/desired amount of EGR, spark timing, air-fuel ratio, etc.

Once the operating conditions are determined, it is determined if the engine is under non-fueling conditions at **304** of routine **300**. Non-fueling conditions include engine operating conditions in which the fuel supply is interrupted but the engine continues spinning and at least one intake valve and one exhaust valve are operating; thus, air is flowing through one or more of the cylinders, but fuel is not injected in the cylinders. Under non-fueling conditions, combustion is not carried out and ambient air may move through the cylinder from the intake passage to the exhaust passage. In this way, a sensor, such as an exhaust gas oxygen sensor, may receive ambient air on which measurements, such as ambient humidity detection, may be performed.

Non-fueling conditions may include, for example, deceleration fuel shut off (DFSO). DFSO is responsive to the operator pedal (e.g., in response to a driver tip-out and where the vehicle accelerates greater than a threshold amount). DSFO conditions may occur repeatedly during a drive cycle, and, thus, numerous indications of the ambient humidity may be generated throughout the drive cycle, such as during each DFSO event. As such, the overall efficiency of the engine may be maintained during driving cycles in which the ambient humidity fluctuates. The ambient humidity may fluctuate due to a change in altitude or temperature or when the vehicle enters/exits fog or rain, for example.

If it is determined that the engine is not operating under non-fueling conditions, for example, fuel is injected in one or more cylinders of the engine, routine **300** moves to **308**. At **308**, the exhaust gas sensor is operated as an air-fuel ratio sensor. In this mode of operation, the sensor may be operated as a lambda sensor, for example. As a lambda sensor, the output voltage may determine whether the exhaust gas air-fuel ratio is lean or rich. Alternatively, the sensor may operate as a universal exhaust gas oxygen sensor (UEGO) and an air-fuel ratio (e.g., a degree of deviation from a stoichiometric ratio) may be obtained from the pumping current of the pumping cell of the sensor.

At **310** of routine **300**, the air-fuel ratio (AFR) is controlled responsive to the exhaust gas oxygen sensor. Thus, a desired exhaust gas AFR may be maintained based on feedback from the sensor during engine fueling conditions. For example, if a desired air-fuel ratio is the stoichiometric ratio and the sensor determines the exhaust gas is lean (i.e., the exhaust gas comprises excess oxygen and the AFR is less than stoichiometric), additional fuel may be injected during subsequent engine fueling operation.

On the other hand, if it is determined that the engine is under non-fueling conditions, the routine proceeds to **306**, and the sensor is operated to determine ambient humidity. The ambient humidity may be determined based on the sensor output, as described in greater detail below with reference to FIG. **4**. For example, a reference voltage of the sensor may be modulated between a minimum voltage at which oxygen is detected and a voltage at which water molecules may be dissociated such that the ambient humidity may be determined. It should be understood, the ambient humidity as determined (described below with reference to FIG. **4**) is the absolute ambient humidity. Additionally, relative humidity may be obtained by further employing a temperature detecting device, such as a temperature sensor.

FIG. **4** shows a flow chart illustrating a routine **400** for determining ambient humidity via an exhaust gas sensor, such as the oxygen sensor described above with reference to FIG. **2**, and positioned as shown in FIG. **1**, for example. Specifically, the routine determines a duration since fuel shut off and determines an ambient humidity via the exhaust gas sensor in a manner based on the duration since fuel shut off. For example, when the duration since fuel shut off is less than a threshold duration, a reference voltage of the sensor is modulated between a first voltage and a second voltage in order to determine the ambient humidity. When the duration since fuel shut off is greater than the threshold duration, the reference voltage is not modulated.

At **402**, the duration since fuel shut off is determined. In some examples, the duration since fuel shut off may be a time since fuel shut off. In other examples, the duration since fuel shut off may be a number of engine cycles since fuel shut off, for example. At **404**, it is determined if the duration since fuel shut off is greater than a threshold duration. The threshold duration may be an amount of time until the exhaust is substantially free of hydrocarbons from combustion in the engine. For example, residual gases from one or more previous combustion cycles may remain in the exhaust for several cycles after fuel is shut off and the gas that is exhausted from the chamber may contain more than ambient air for a duration after fuel injection is stopped. Further, the period in which fuel is shut off may vary. For example, a vehicle operator may release the accelerator pedal and coast to a stop, resulting in a long DFSO period. In some situations, the fuel shut off period (the time from interruption of the fuel supply to restart of the fuel supply, for example) may not be long enough for the ambient air to establish an equilibrium state in the exhaust system. For example, a vehicle operator may tip-in shortly after releasing the accelerator pedal, causing DFSO to stop soon after beginning. In such a situation, routine **400** proceeds to **406**.

If it is determined that the duration is less than the threshold duration, the routine continues to **406** and the sensor is operated in a first mode in which the reference voltage is modulated between a first voltage and a second voltage. As one non-limiting example, the first voltage may be 450 mV and the second voltage may be 950 mV. At 450 mV, for example, the pumping current may be indicative of an amount of oxygen in the exhaust gas. At 950 mV, water molecules may be dissociated such that the pumping current is indicative of the amount of oxygen in the exhaust gas plus an amount of oxygen from dissociated water molecules. The first voltage may be a voltage at which a concentration of oxygen in the exhaust gas may be determined, for example, while the second voltage may be a voltage at which water molecules may be dissociated. In this way, a humidity of the exhaust gas may be determined based on the water concentration.

In another example, the first voltage is 450 mV and the second voltage is 1080 mV. At 1080 mV, carbon dioxide (CO_2) molecules may be dissociated in addition to water molecules. In such an example, an amount of alcohol (e.g, ethanol) in the fuel may be determined based on the average change in pumping current while the voltage is modulated.

Continuing with FIG. **4**, at **408**, a change in pumping current during the modulation is determined. For example, the difference in pumping current at the first reference voltage and the pumping current at the second reference voltage is determined. FIG. **5** shows a graph illustrating an example of a modulated reference voltage **502** and corresponding change in pumping current **504** during a non-fueling condition such as DFSO. In the example depicted in FIG. **5**, DFSO begins at a time t_1 and ends at a time t_2. As shown, the reference voltage **502** is modulated between a first voltage V_1 and a second voltage V_2, which is higher than the first voltage V_1. Responsive to the changing reference voltage **502**, the pumping current **504** also changes. Thus, a change in pumping current (e.g., a delta pumping current) may be determined. The delta pumping current may be averaged over the duration of the DFSO condition such that an ambient humidity may be determined.

Continuing with FIG. **4**, at **410** of routine **400**, the average change in pumping current is determined. Once the average change in pumping current is determined, a first indication of ambient humidity is determined based on the average change in pumping current at **412**. By modulating the reference voltage and determining an average change in pumping current, the effect of a changing air fuel ratio at the beginning of a fuel shut off duration when residual combustion gases may be present in the exhaust may be nullified, for example. As such, an indication of ambient humidity may be generated relatively quickly after fuel injection is suspended, even if the exhaust gas is not free of residual combustion gases.

Referring back to **404**, if it is determined that the duration since fuel shut off is greater than the threshold duration, the routine moves to **414** and the sensor is operated in a second mode in which the reference voltage is increased to a threshold voltage, but not modulated. The threshold voltage may be a voltage at which a desired molecule is dissociated. As an example, the reference voltage may be increased to 950 mV or another voltage at which water molecules may be dissociated. At **416**, the change in pumping current due to the increased reference voltage is determined. At **418**, a second indication of ambient humidity is determined based on the change in pumping current determined at **416**. After the threshold duration, the exhaust gas may be free from residual combustion gases. As such, an indication of ambient humidity may be generated without modulating the reference voltage at a rapid rate.

As described in detail above, an exhaust gas sensor may be operated in at least two modes in which the pumping voltage or pumping current of the pumping cell is monitored. As such, the sensor may be employed to determine the absolute ambient humidity of the air surrounding the vehicle as well as the air-fuel ratio of the exhaust gas. Subsequent to detection of the ambient humidity, a plurality of engine operating parameters may be adjusted for optimal engine performance, which will be explained in detail below. These parameters include, but are not limited to, an amount of exhaust gas recirculation (EGR), spark timing, air-fuel ratio, fuel injection, and valve timing. In one embodiment, one or more of these operating parameters (e.g., EGR, spark timing, air-fuel ratio, fuel injection, valve timing, etc.) are not adjusted during the modulating of the reference voltage

FIG. **6** shows a flow chart illustrating a routine **600** for adjusting engine operating parameters based on an ambient humidity generated by an exhaust gas sensor such as the ambient humidity generated as described with reference to FIG. **4**, for example. Specifically, the routine determines the humidity and adjusts one or more operating parameters based on the humidity. For example, an increase in water concentration of the air surrounding the vehicle may dilute a charge mixture delivered to a combustion chamber of the engine. If one or more operating parameters are not adjusted in response to the increase in humidity, engine performance and fuel economy may decrease and emissions may increase; thus, the overall efficiency of the engine may be reduced.

At **602**, engine operating conditions are determined. The engine operating conditions may include EGR, spark timing, and air fuel ratio, among others, which may be affected by fluctuations of the water concentration in ambient air.

Once the operating conditions are determined, the routine proceeds to **604** where the ambient humidity is determined. The ambient humidity may be determined based on an exhaust gas sensor, such as the exhaust gas sensor described above with reference to FIG. **2**. For example, the ambient humidity may be determined based on **412** or **418** of routine **400** described with reference to FIG. **4**.

Once the ambient humidity is determined, the routine continues to **606** where one or more operating parameters are adjusted based on the ambient humidity. Such operating parameters may include an amount of EGR, spark timing, and air-fuel ratio, among others. As described above, in internal combustion engines, it is desirable to schedule engine operating parameters, such as spark timing, in order to optimize engine performance. In some embodiments, only one parameter may be adjusted responsive to the humidity. In other embodiments, any combination or subcombination of these operating parameters may be adjusted in response to measured fluctuations in ambient humidity.

In one example embodiment, an amount of EGR may be adjusted based on the measured ambient humidity. For example, in one condition, the water concentration in the air surrounding the vehicle may have increased due to a weather condition such as fog; thus, a higher humidity is detected by the exhaust gas sensor during engine non-fueling conditions. In response to the increased humidity measurement, during subsequent engine fueling operation, the EGR flow into at least one combustion chamber may be reduced. As a result, engine efficiency may be maintained.

Responsive to a fluctuation in absolute ambient humidity, EGR flow may be increased or decreased in at least one combustion chamber. As such, the EGR flow may be increased or decreased in only one combustion chamber, in some combustion chambers, or in all combustion chambers. Furthermore, the magnitude of change of the EGR flow may be the same for all cylinders or the magnitude of change of the EGR flow may vary by cylinder based on the specific operating conditions of each cylinder.

In another embodiment, spark timing may be adjusted responsive to the ambient humidity. In at least one condition, for example, spark timing may be advanced in one or more cylinders during subsequent engine fueling operation responsive to a higher humidity reading. Spark timing may be scheduled so as to reduce knock in low humidity conditions (e.g., retarded from a peak torque timing), for example. When an increase in humidity is detected by the exhaust gas sensor, spark timing may be advanced in order to maintain engine performance and operate closer to or at a peak torque spark timing.

Additionally, spark timing may be retarded in response to a decrease in ambient humidity. For example, a decrease in ambient humidity from a higher humidity may cause knock. If the decrease in humidity is detected by the exhaust gas sensor during non-fueling conditions, such as DFSO, spark timing may be retarded during subsequent engine fueling operation and knock may be reduced.

It should be noted that spark may be advanced or retarded in one or more cylinders during subsequent engine fueling operation. Further, the magnitude of change of spark timing may be the same for all cylinders or one or more cylinders may have varying magnitudes of spark advance or retard.

In still another example embodiment, exhaust gas air fuel ratio may be adjusted responsive to the measured ambient humidity during subsequent engine fueling operation. For example, an engine may be operating with a lean air fuel ratio optimized for low humidity. In the event of an increase in humidity, the mixture may become diluted, resulting in engine misfire. If the increase in humidity is detected by the exhaust gas sensor during non-fueling conditions, however, the air fuel ration may be adjusted so that the engine will operate with a less lean, lean air fuel ratio during subsequent fueling operation. Likewise, an air fuel ratio may be adjusted to be a more lean, lean air fuel ratio during subsequent engine fueling operation in response to a measured decrease in ambient humidity. In this way, conditions such as engine misfire due to humidity fluctuations may be reduced.

In some examples, an engine may be operating with a stoichiometric air fuel ratio or a rich air fuel ratio. As such, the air fuel ratio may be independent of ambient humidity and measured fluctuations in humidity may not result in an adjustment of air fuel ratio.

In this way, engine operating parameters may be adjusted responsive to an ambient humidity generated by an exhaust gas sensor coupled to an engine exhaust system. As DFSO may occur numerous times during a drive cycle, an ambient humidity measurement may be generated several times throughout the drive cycle and one or more engine operating parameters may be adjusted accordingly, resulting in an optimized overall engine performance despite fluctuations in ambient humidity. Furthermore, the engine operating parameters may be adjusted responsive to the ambient humidity regardless of a duration the engine non-fueling conditions, as an indication of ambient humidity may be generated in a short amount of time even if the exhaust gas is not devoid of residual combustion gases by modulating the reference voltage.

Note that the example control and estimation routines included herein can be used with various engine and/or vehicle system configurations. The specific routines described herein may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various acts, operations, or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the features and advantages of the example embodiments described herein, but is provided for ease of illustration and description. One or more of the illustrated acts or functions may be repeatedly performed depending on the particular strategy being used. Further, the described acts may graphically represent code to be programmed into the computer readable storage medium in the engine control system.

It will be appreciated that the configurations and routines disclosed herein are exemplary in nature, and that these specific embodiments are not to be considered in a limiting sense, because numerous variations are possible. For example, the above technology can be applied to V-6, I-4, I-6, V-12, opposed 4, and other engine types. The subject matter of the present disclosure includes all novel and nonobvious combinations and subcombinations of the various systems and configurations, and other features, functions, and/or properties disclosed herein.

The following claims particularly point out certain combinations and subcombinations regarded as novel and nonobvious. These claims may refer to "an" element or "a first" element or the equivalent thereof. Such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements. Other combinations and subcombinations of the disclosed features, functions, elements, and/or properties may be claimed through amendment of the present claims or through presentation of new claims in this or a related application.

Such claims, whether broader, narrower, equal, or different in scope to the original claims, also are regarded as included within the subject matter of the present disclosure.

The invention claimed is:

1. A method for an engine system, comprising:

during engine non-fueling conditions, where at least one intake valve and one exhaust valve are operating and a duration since fuel shut off is less than a threshold duration:

modulating a reference voltage of an exhaust gas sensor between a first reference voltage and a second reference voltage;

generating an indication of ambient humidity based on an average change in pumping current of the sensor during the modulating; and

during subsequent engine fueling conditions, adjusting an engine actuator based on the indication of ambient humidity.

2. The method of claim 1, wherein the sensor is an exhaust gas oxygen sensor.

3. The method of claim 1, wherein the engine non-fueling conditions include deceleration fuel shut off.

4. The method of claim 1, wherein the engine actuator adjusts an amount of exhaust gas recirculation, and, in at least one condition, adjusting the amount of exhaust gas recirculation includes reducing the amount of exhaust gas recirculation responsive to an indication of higher humidity.

5. The method of claim 1, further comprising, after the duration since fuel shut off is greater than the threshold duration, generating a second indication of ambient humidity based on the sensor without modulating the reference voltage.

6. The method of claim 1, wherein the engine actuator adjusts an engine combustion air fuel ratio, and adjusting the air fuel ratio includes maintaining a desired exhaust air fuel ratio based on the sensor.

7. The method of claim 1, wherein the ambient humidity is an absolute humidity and wherein the duration since fuel shut off is one of a time since fuel shut off or a number of engine cycles since fuel shut off.

8. The method of claim 1, wherein modulating the reference voltage includes switching the reference voltage between the first voltage and the second voltage at a rate.

9. The method of claim 8, wherein the first voltage is 450 mV and the second voltage is 950 mV.

10. The method of claim 8, wherein generating the indication of ambient humidity includes averaging a change in pumping current for each modulation between the first voltage and the second voltage.

11. A method for an exhaust gas sensor coupled in an exhaust passage of an engine, comprising:

during engine non-fueling conditions, where at least one intake valve and one exhaust valve are operating:

during a first condition when a duration since fuel shut off is less than a threshold duration:

modulating a reference voltage between a first voltage and a second voltage; and

determining a first indication of ambient humidity based on an average change in pumping current during the modulating; and

during a second condition when the duration since fuel shut off is greater than the threshold duration:

increasing the reference voltage to a threshold voltage and not modulating the reference voltage; and

determining a second indication of ambient humidity based on a change in pumping current upon increasing the reference voltage to the second voltage; and

during subsequent engine fueling conditions, adjusting an engine actuator based on one of the first indication of ambient humidity and the second indication of ambient humidity.

12. The method of claim 11, wherein the first voltage is 450 mV and the second voltage is 950 mV.

13. The method of claim 11, wherein the threshold voltage is a voltage at which water molecules are dissociated.

14. The method of claim 11, wherein the sensor is an exhaust gas oxygen sensor, and wherein the non-fueling conditions include deceleration fuel shut off.

15. The method of claim 11, wherein the engine actuator adjusts one or more of an amount of exhaust gas recirculation, spark timing, and engine air fuel ratio.

16. The method of claim 15, wherein adjusting the amount of exhaust gas recirculation includes increasing the amount of exhaust gas recirculation responsive to an indication of lower humidity.

17. The method of claim 15, wherein adjusting the spark timing includes advancing the spark timing responsive to an indication of higher humidity.

18. The method of claim 15, wherein adjusting the engine air fuel ratio includes increasing a lean air fuel ratio responsive to an indication of higher humidity.

19. A system, comprising:

an engine with an exhaust system;

an exhaust gas oxygen sensor disposed in the exhaust system; and

a control system in communication with the sensor, the control system including non-transitory instructions to:

shut off engine fueling; and

following shutting off engine fueling and before a threshold duration since fuel shut off, modulate a reference voltage of the sensor between a first voltage and a second voltage, and generate a first indication of ambient humidity based on a change in pumping current responsive to the modulation of the reference voltage; following shutting off engine fueling and after the threshold duration since fuel shut off, increase the reference voltage to the second voltage and not modulate the reference voltage, and generate a second indication of ambient humidity based on a change in pumping current responsive to the change in reference voltage; and, during subsequent engine fueling conditions, adjust one or more engine operating parameters based on one of the first indication of ambient humidity and the second indication of ambient humidity.

20. The system of claim 19, wherein the engine operating parameters include an amount of exhaust gas recirculation, engine air fuel ratio, and spark timing.

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